

# Critical tests of unintegrated gluon distributions

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We use the unintegrated Parton Density Functions of the gluon obtained from a fit to measurements of the structure functions  $F_2(x, Q^2)$  and  $F_2^c(x, Q^2)$  at HERA to describe the experimental data for  $F_2^b(x, Q^2)$ ,  $F_L(x, Q^2)$  and  $F_L$  at fixed  $W$ .

## 1 Introduction

The purpose of the present investigation is to study the longitudinal structure function (SF)  $F_L(x, Q^2)$  as well as the charm and beauty contributions to the proton SF  $F_2(x, Q^2)$  using the  $k_T$ -factorization approach of QCD [1]. The SF  $F_L(x, Q^2)$  is directly connected to the gluon density in the proton. Only in the naive quark-parton-model  $F_L(x, Q^2) = 0$ , and becomes non-zero in pQCD. However the pQCD leads to controversial results still. It was shown recently [2], that the  $F_L$  experimental data from HERA seem to be inconsistent with some of the NLO predictions (in particular the MRST one) at small  $x$ . BFKL effects significantly improve the description of the low  $x$  data when compared to a standard NLO  $\overline{MS}$ -scheme global fit. The NNLO global fit becomes better when taking into account higher order terms involving powers of  $\ln(1/x)$ . It means, that we need a resummation procedure.

On the other hand it is known, that the BFKL effects are taken into account from the very beginning in the  $k_T$ -factorization approach [1], which is based on the BFKL [3] or CCFM [4] evolution equations summing up the large logarithmic terms proportional to  $\ln(1/x)$  or  $\ln(1/(1-x))$  in the LLA. Some applications of the  $k_T$ -factorization approach were shown in Refs. [5]. In the framework of  $k_T$ -factorization the study of the longitudinal SF  $F_L$  began already ten years ago [6], where the small  $x$  asymptotics of  $F_L$  has been evaluated, using the BFKL results. Since we want to analyze the SF data in a broader range at small  $x$  we use a more phenomenological approach in our analyses of  $F_2$  and  $F_L$  data [7, 8]. Using the  $k_T$ -factorization approach for the description of different SF at small  $x$  we hope to obtain additional information (or restrictions), in particular, about one of the main ingredient of  $k_T$ -factorization approach - the unintegrated gluon distribution (UGD)

In the  $k_T$ -factorization the SF  $F_{2,L}(x, Q^2)$  are driven at small  $x$  primarily by gluons and are related in the following way to the UGD  $x\mathcal{A}(x, \mathbf{k}_T^2, \mu^2)$

$$F_{2,L}(x, Q^2) = \int_x^1 \frac{dz}{z} \int^{Q^2} dk_T^2 \sum_{i=u,d,s,c} e_i^2 \hat{C}_{2,L}^g(x/z, Q^2, m_i^2, k_T^2) x\mathcal{A}(x, \mathbf{k}_T^2, \mu^2). \quad (1)$$

The functions  $\hat{C}_{2,L}^g(x, Q^2, m_i^2, k_T^2)$  can be regarded as SF of the off-shell gluons with virtuality  $k_T^2$  (hereafter we call them *hard structure functions*). They are described by the sum of the quark box (and crossed box) diagram contribution to the photon-gluon interaction.

To apply Eq.(1) for SF at low  $Q^2$  we change the low  $Q^2$  asymptotics of the QCD coupling constant within hard structure functions. We have used the so called "freezing" procedure in the "soft" form, when the argument of the strong coupling constant is shifted from  $Q^2$  to  $Q^2 + M^2$  [9]. Then  $\alpha_s = \alpha_s(Q^2 + M^2)$ . For massless quarks  $M = m_\rho$  and for massive ones with mass  $m_Q$ ,  $M = 2m_Q$ .

To calculate the SF  $F_2^{c,b}$  and  $F_L(x, Q^2)$  we used the hard SF  $\hat{C}_{2,L}^g(x, Q^2, m^2, k_T^2)$  from Ref. [8, 10]<sup>a</sup> and two UGD  $\mathcal{A}(x, \mathbf{k}_T^2, \mu^2)$  obtained in our previous paper [12]. These UGD are determined by a convolution of the non-perturbative starting distribution  $\mathcal{A}_0(x)$  and CCFM evolution denoted by  $\bar{\mathcal{A}}(x, \mathbf{k}_T^2, \mu^2)$ :

$$x\mathcal{A}(x, \mathbf{k}_T^2, \mu^2) = \int dz \mathcal{A}_0(z) \frac{x}{z} \bar{\mathcal{A}}\left(\frac{x}{z}, \mathbf{k}_T^2, \mu^2\right), \quad (2)$$

where

$$x\mathcal{A}_0(x) = Nx^{-B_g}(1-x)^{C_g}(1-D_gx). \quad (3)$$

The parameters  $N, B_g, C_g, D_g$  of  $\mathcal{A}_0$  were determined in the fits to  $F_2$  and  $F_2^c$  data [13, 14] independently (see [12]) Fig. 1 shows the two different UGD. The small  $x$  behaviour of these UGD is very different<sup>b</sup>.

To calculate the SF  $F_2^b(x, Q^2)$  and  $F_L(x, Q^2)$  we took  $m_c = 1.4$  GeV and  $m_b = 4.75$  GeV and used the  $m^2 = 0$  limit of the above Eq. 1 to evaluate the corresponding lightquark contributions to the  $F_L$ . Fig. 2 (left panel) shows the  $F_2^b$  as a function of  $x$  at fixed  $Q^2$ . Fig.2 (right panel) shows the  $F_L$  as a function of  $x$  at fixed  $Q^2$ . Fig. 3 shows the SF  $F_L(Q^2)$  at fixed  $W$  compared to the H1 data [17]. It is interesting to observe, that the measured  $F_2^b$  seems to prefer the UGD obtained from the fit to  $F_2$  and is inconsistent with the one obtained from  $F_2^c$ . Also the measured  $F_L$  is better described with the UGD from the  $F_2$  fit. In summary the  $k_T$ -factorization approach with the CCFM-evolved UGD obtained from the fits to the  $F_2(x, Q^2)$  data reproduces the H1 data for SF  $F_2^b(x, Q^2)$ ,  $F_L(x, Q^2)$  and  $F_L$  at fixed  $W$  (see [12]). The UGD obtained from the fit to  $F_2^c$  seems to overshoot the measured  $F_2^b$  and  $F_L$  at small  $x$ . New experimental data for  $F_L(x, Q^2)$  but also more precise measurements of the heavy quark structure functions are very important for a precise determination of the UGD.

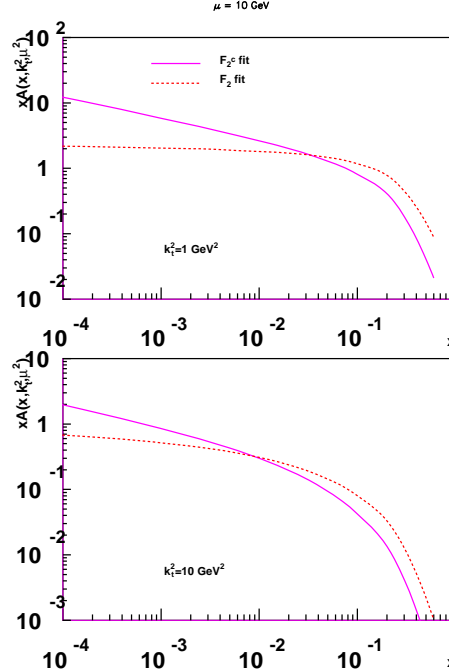


Figure 1: UGD obtained in the fits to  $F_2^c$  (solid curve) and  $F_2$  (dotted curve)

<sup>a</sup>There is full agreement of our results with the formulae for the photoproduction of heavy quarks from Ref. [11].

<sup>b</sup>See also Ref. [15].

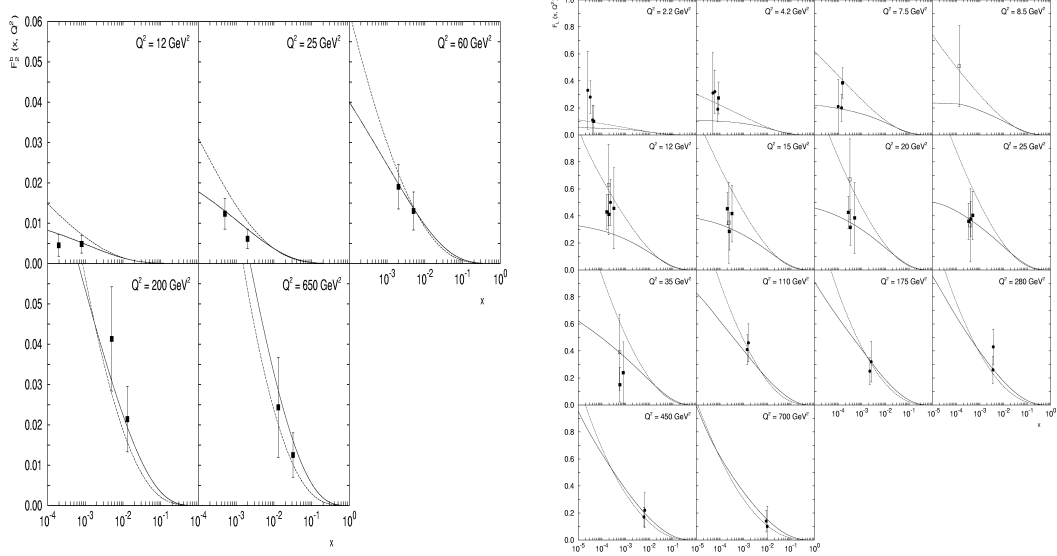


Figure 2: The SF  $F_2^b$  as a function of  $x$  at fixed  $Q^2$  compared to the H1 data [14](left panel) The solid and dotted lines are from CCFM-evolved UGD obtained from the fits to  $F_2(x, Q^2)$  and  $F_2^c(x, Q^2)$ . The SF  $F_L$  as a function of  $x$  at fixed  $Q^2$  compared to the H1 data [13, 16](right panel) The solid and dotted lines are from CCFM-evolved UGD obtained from the fits to  $F_2(x, Q^2)$  and  $F_2^c(x, Q^2)$ .

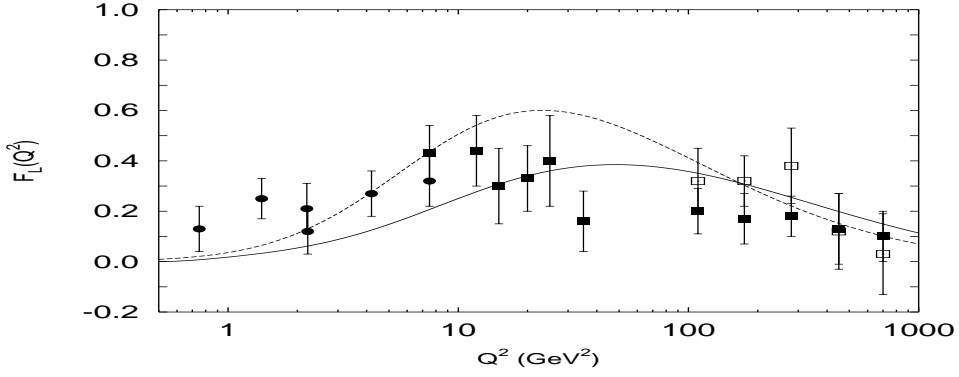


Figure 3: The  $Q^2$  dependence of SF  $F_L(Q^2)$  at fixed  $W = 276$  GeV compared to the H1 data [17] The solid and dotted lines are from CCFM-evolved UGD obtained from the fits to  $F_2(x, Q^2)$  and  $F_2^c(x, Q^2)$ .

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